



SCHOOL OF ENGINEERING

MAIN EXAMINATIONS: NOVEMBER 2025

COURSE AND CODE: CHEMICAL ENGINEERING PRINCIPLES ENCH1EB

DURATION: 2 HOURS

TOTAL MARKS: 100

INTERNAL EXAMINER/S: DR N MASEKO
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EXTERNAL MODERATOR: PROF. K TUMBA

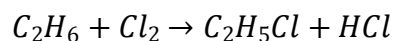
INSTRUCTIONS:

1. **ALL** questions should be attempted. Answer in **INK**.
2. Any programmable or non-programmable calculator may be used provided it has been cleared of any information that would subvert the purpose of the examination.
3. Calculations must be shown in sufficient detail to illustrate your understanding of the procedure.
4. **Two answer books are provided. Label them Book A and Book B. Answer Section A in Book A and Section B in Book B.**
5. This examination question paper, together with all associated diagrams, **MUST BE HANDED IN TOGETHER WITH YOUR SCRIPT.**

Student Number:

SECTION A**QUESTION 1**

Hydrogen chloride is formed through the chlorination of ethane in a continuous reactor where a 60% single pass conversion of ethane is reported according to the following balanced chemical reaction:



The molar flow rate of Inert fed into the reactor is 11 mol/h while unreacted ethane found in the reactor effluent stream is 13.4 mol/h. Stream P is a product stream with only monochloroethane and hydrogen chloride. Unreacted ethane, chlorine and inert are recycled back into the process while some of it is purged out of the system. The molar flowrate of the purge stream is 17.2 mol/h

The flowchart of this chlorination reaction is shown in Figure 1 below:

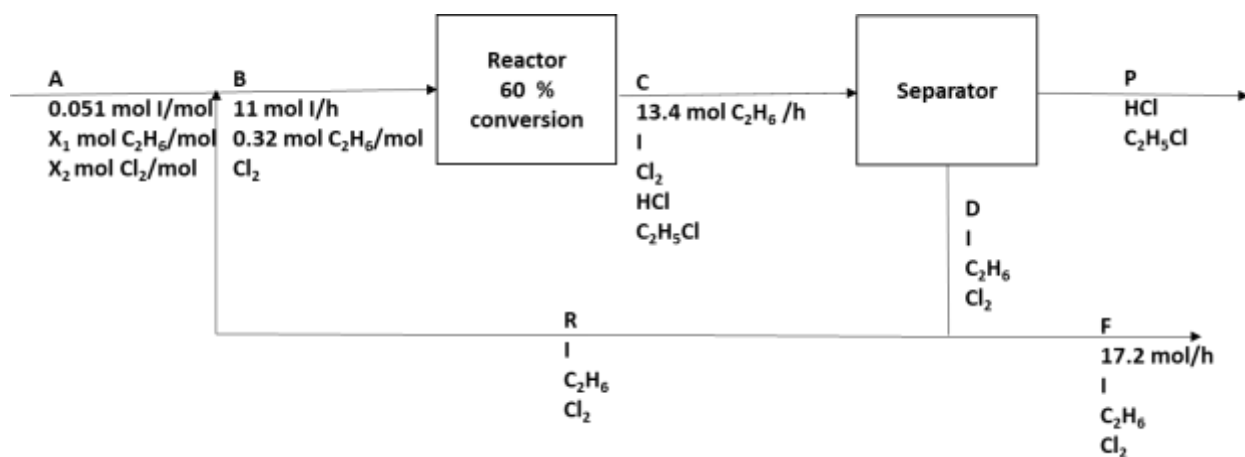


Figure 1: Chlorination reaction of ethane

- Calculate the flow rates of the reactor feed and the reactor effluent stream (12)
- Calculate the flow rates of the recycle and fresh feed stream (5)
- Calculate x_1 and x_2 (6)
- What is the overall conversion of ethane?

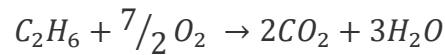
e) Name one function of the recycle stream

(4)

(2)

TOTAL /29/**QUESTION 2**

Ethane is burned with air. No carbon monoxide is present in combustion products.



Use a basis of 120 mol/s of ethane fed.

a) Draw and fully label a flowchart of the process described above.

(3)

b) Calculate the molar flow rates of all the gases in the exit stream when there is 90% ethane conversion and air is 25% in excess.

(13)

c) What is the mole fraction of CO₂ in the exit stream?

(3)

d) Calculate the extent of reaction of the above reaction

(2)

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SECTION B**QUESTION 3**

In a heat exchanger, 1 kg/s of a mixture of benzene and toluene (mass fraction of benzene 0.5 kg/kg) is being heated in the tubes from 10°C to 75°C. The heat to achieve this is provided by steam entering the shell side at 1 bar pressure and 150°C which cools and condenses to saturated water at 1 bar pressure.

- a) What is the enthalpy change of the benzene/toluene mixture in kJ/s?
(12)
- b) What is the mass flow rate of steam required in kg/s?
(6)

Data:

For benzene C_p (liquid) = $0.1265 + 0.000234T$ kJ/mol.°C, Molecular weight = 78.11 g/mol

For toluene C_p (liquid) = $0.1488 + 0.000324T$ kJ/mol.°C, Molecular weight = 92.13 g/mol

Steam tables are provided on pages 5 and 6

TOTAL /18/

QUESTION 4

1m³/s of steam at 400°C and 5 bar pressure is being mixed with 0.5m³/s of saturated steam at 1 bar pressure, and leaves at 5 bar pressure. What will be the mass flowrate (in kg/s) and specific enthalpy (in kJ/kg) of the mixed and compressed steam stream and its temperature?

Steam tables are provided on page 5 and 6

TOTAL /12/

QUESTION 5

In a furnace, 100 mol/s of butane gas at 25°C is being fully combusted in 5714 mol/s of air fed to the furnace at 200°C. Energy is removed from the furnace to superheat steam at 1 bar pressure. The flue gas mixture leaves the furnace at 300°C. Determine:

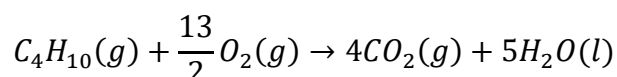
- a) The standard heat of combustion of the butane from the heat of formation data given in the table below.

(5)

- b) The amount of heat removed from the furnace per second to superheat steam.

(15)

Combustion reaction for butane at 25°C, 1 atm pressure:

**Data**

Heat of Formation data:

Compound	Heat of Formation (kJ/mol)
C ₄ H ₁₀ (g)	-124.7
CO ₂ (g)	-393.5
H ₂ O (l)	-285.84

Data for water:

$$C_p (\text{liquid}) = 0.0754 \text{ kJ/mol.}^\circ\text{C}$$

$$\Delta H_v = 40.656 \text{ kJ/mol at } T_b = 100^\circ\text{C}$$

$$C_p (\text{gas}) = 0.03346 + 0.00000688T \text{ kJ/mol.}^\circ\text{C}$$

A table of specific enthalpies for selected gases is provided on page 7

TOTAL /20/

Table B.7 Properties of Superheated Steam^a

P(bar) (T _{sat} , °C)		Sat'd Water	Sat'd Steam	Temperature (°C) →							
				50	75	100	150	200	250	300	350
0.0 (—)	$\hat{H}$	—	—	2595	2642	2689	2784	2880	2978	3077	3177
	$\hat{U}$	—	—	2446	2481	2517	2589	2662	2736	2812	2890
	$\hat{V}$	—	—	—	—	—	—	—	—	—	—
0.1 (45.8)	$\hat{H}$	191.8	2584.8	2593	2640	2688	2783	2880	2977	3077	3177
	$\hat{U}$	191.8	2438.0	2444	2480	2516	2588	2661	2736	2812	2890
	$\hat{V}$	0.00101	14.7	14.8	16.0	17.2	19.5	21.8	24.2	26.5	28.7
0.5 (81.3)	$\hat{H}$	340.6	2646.0	209.3	313.9	2683	2780	2878	2979	3076	3177
	$\hat{U}$	340.6	2484.0	209.2	313.9	2512	2586	2660	2735	2811	2889
	$\hat{V}$	0.00103	3.24	0.00101	0.00103	3.41	3.89	4.35	4.83	5.29	5.75
1.0 (99.6)	$\hat{H}$	417.5	2675.4	209.3	314.0	2676	2776	2875	2975	3074	3176
	$\hat{U}$	417.5	2506.1	209.2	313.9	2507	2583	2658	2734	2811	2889
	$\hat{V}$	0.00104	1.69	0.00101	0.00103	1.69	1.94	2.17	2.40	2.64	2.87
5.0 (151.8)	$\hat{H}$	640.1	2747.5	209.7	314.3	419.4	632.2	2855	2961	3065	3168
	$\hat{U}$	639.6	2560.2	209.2	313.8	418.8	631.6	2643	2724	2803	2883
	$\hat{V}$	0.00109	0.375	0.00101	0.00103	0.00104	0.00109	0.425	0.474	0.522	0.571
10 (179.9)	$\hat{H}$	762.6	2776.2	210.1	314.7	419.7	632.5	2827	2943	3052	3159
	$\hat{U}$	761.5	2582	209.1	313.7	418.7	631.4	2621	2710	2794	2876
	$\hat{V}$	0.00113	0.194	0.00101	0.00103	0.00104	0.00109	0.206	0.233	0.258	0.282
20 (212.4)	$\hat{H}$	908.6	2797.2	211.0	315.5	420.5	633.1	852.6	2902	3025	3139
	$\hat{U}$	906.2	2598.2	209.0	313.5	418.4	603.9	850.2	2679	2774	2862
	$\hat{V}$	0.00118	0.09950	0.00101	0.00102	0.00104	0.00109	0.00116	0.111	0.125	0.139
40 (250.3)	$\hat{H}$	1087.4	2800.3	212.7	317.1	422.0	634.3	853.4	1085.8	2962	3095
	$\hat{U}$	1082.4	2601.3	208.6	313.0	417.8	630.0	848.8	1080.8	2727	2829
	$\hat{V}$	0.00125	0.04975	0.00101	0.00102	0.00104	0.00109	0.00115	0.00125	0.0588	0.0665
60 (275.6)	$\hat{H}$	1213.7	2785.0	214.4	318.7	423.5	635.6	854.2	1085.8	2885	3046
	$\hat{U}$	1205.8	2590.4	208.3	312.6	417.3	629.1	847.3	1078.3	2668	2792
	$\hat{V}$	0.00132	0.0325	0.00101	0.00103	0.00104	0.00109	0.00115	0.00125	0.0361	0.0422
80 (295.0)	$\hat{H}$	1317.1	2759.9	216.1	320.3	425.0	636.8	855.1	1085.8	2787	2990
	$\hat{U}$	1306.0	2571.7	208.1	312.3	416.7	628.2	845.9	1075.8	2593	2750
	$\hat{V}$	0.00139	0.0235	0.00101	0.00102	0.00104	0.00109	0.00115	0.00124	0.0243	0.0299
100 (311.0)	$\hat{H}$	1408.0	2727.7	217.8	322.9	426.5	638.1	855.9	1085.8	1343.4	2926
	$\hat{U}$	1393.5	2547.3	207.8	311.7	416.1	627.3	844.4	1073.4	1329.4	2702
	$\hat{V}$	0.00145	0.0181	0.00101	0.00102	0.00104	0.00109	0.00115	0.00124	0.00140	0.0224
150 (342.1)	$\hat{H}$	1611.0	2615.0	222.1	326.0	430.3	641.3	858.1	1086.2	1338.2	2695
	$\hat{U}$	1586.1	2459.9	207.0	310.7	414.7	625.0	841.0	1067.7	1317.6	2523
	$\hat{V}$	0.00166	0.0103	0.00101	0.00102	0.00104	0.00108	0.00114	0.00123	0.00138	0.0115
200 (365.7)	$\hat{H}$	1826.5	2418.4	226.4	330.0	434.0	644.5	860.4	1086.7	1334.3	1647.1
	$\hat{U}$	1785.7	2300.8	206.3	309.7	413.2	622.9	837.7	1062.2	1307.1	1613.7
	$\hat{V}$	0.00204	0.005875	0.00100	0.00102	0.00103	0.00108	0.00114	0.00122	0.00136	0.00167
221.2(P _c) (374.15)(T _c)	$\hat{H}$	2108	2108	228.2	331.7	435.7	645.8	861.4	1087.0	1332.8	1635.5
	$\hat{U}$	2037.8	2037.8	206.0	309.2	412.8	622.0	836.3	1060.0	1302.9	1600.3
	$\hat{V}$	0.00317	0.00317	0.00100	0.00102	0.00103	0.00108	0.00114	0.00122	0.00135	0.00163
250	$\hat{H}$	—	—	230.7	334.0	437.8	647.7	862.8	1087.5	1336.4	1638.0

Table B.7 (Continued)

$P(\text{bar})$ ($T_{\text{sat}}, ^\circ\text{C}$)		Temperature ($^\circ\text{C}$) →							
		400	450	500	550	600	650	700	750
0.0 (—)	$\hat{H}$	3280	3384	3497	3597	3706	3816	3929	4043
	$\hat{U}$	2969	3050	3132	3217	3303	3390	3480	3591
	$\hat{V}$	—	—	—	—	—	—	—	—
0.1 (45.8)	$\hat{H}$	3280	3384	3489	3596	3706	3816	3929	4043
	$\hat{U}$	2969	3050	3132	3217	3303	3390	3480	3571
	$\hat{V}$	21.1	33.3	35.7	38.0	40.3	42.6	44.8	47.2
0.5 (81.3)	$\hat{H}$	3279	3383	3489	3596	3705	3816	3929	4043
	$\hat{U}$	2969	3049	3132	3216	3302	3390	3480	3571
	$\hat{V}$	6.21	6.67	7.14	7.58	8.06	8.55	9.01	9.43
1.0 (99.6)	$\hat{H}$	3278	3382	3488	3596	3705	3816	3928	4042
	$\hat{U}$	2968	3049	3132	3216	3302	3390	3479	3570
	$\hat{V}$	3.11	3.33	3.57	3.80	4.03	4.26	4.48	4.72
5.0 (151.8)	$\hat{H}$	3272	3379	3484	3592	3702	3813	3926	4040
	$\hat{U}$	2964	3045	3128	3213	3300	3388	3477	3569
	$\hat{V}$	0.617	0.664	0.711	0.758	0.804	0.850	0.897	0.943
10 (179.9)	$\hat{H}$	3264	3371	3478	3587	3697	3809	3923	4038
	$\hat{U}$	2958	3041	3124	3210	3296	3385	3475	3567
	$\hat{V}$	0.307	0.330	0.353	0.377	0.402	0.424	0.448	0.472
20 (212.4)	$\hat{H}$	3249	3358	3467	3578	3689	3802	3916	4032
	$\hat{U}$	2946	3031	3115	3202	3290	3379	3470	3562
	$\hat{V}$	0.151	0.163	0.175	0.188	0.200	0.211	0.223	0.235
40 (250.3)	$\hat{H}$	3216	3331	3445	3559	3673	3788	3904	4021
	$\hat{U}$	2922	3011	3100	3188	3278	3368	3460	3554
	$\hat{V}$	0.0734	0.0799	0.0864	0.0926	0.0987	0.105	0.111	0.117
60 (275.6)	$\hat{H}$	3180	3303	3422	3539	3657	3774	3892	4011
	$\hat{U}$	2896	2991	3083	3174	3265	3357	3451	3545
	$\hat{V}$	0.0474	0.0521	0.0566	0.0609	0.0652	0.0693	0.0735	0.0776
80 (295.0)	$\hat{H}$	3142	3274	3399	3520	3640	3759	3879	4000
	$\hat{U}$	2867	2969	3065	3159	3252	3346	3441	3537
	$\hat{V}$	0.0344	0.0382	0.0417	0.0450	0.0483	0.0515	0.0547	0.0578
100 (311.0)	$\hat{H}$	3100	3244	3375	3500	3623	3745	3867	3989
	$\hat{U}$	2836	2946	3047	3144	3240	3335	3431	3528
	$\hat{V}$	0.0264	0.0298	0.0328	0.0356	0.0383	0.0410	0.0435	0.0461
150 (342.1)	$\hat{H}$	2975	3160	3311	3448	3580	3708	3835	3962
	$\hat{U}$	2744	2883	2999	3105	3207	3307	3407	3507
	$\hat{V}$	0.0157	0.0185	0.0208	0.0229	0.0249	0.0267	0.0286	0.0304
200 (365.7)	$\hat{H}$	2820	3064	3241	3394	3536	3671	3804	3935
	$\hat{U}$	2622	2810	2946	3063	3172	3278	3382	3485
	$\hat{V}$	0.009950	0.0127	0.0148	0.0166	0.0182	0.0197	0.0211	0.0225
221.2(P_c) (374.15)(T_c)	$\hat{H}$	2733	3020	3210	3370	3516	3655	3790	3923
	$\hat{U}$	2553	2776	2922	3045	3157	3265	3371	3476
	$\hat{V}$	0.008157	0.0110	0.0130	0.0147	0.0162	0.0176	0.0190	0.0202
250 (—)	$\hat{H}$	2582	2954	3166	3337	3490	3632	3772	3908
	$\hat{U}$	2418	2748	2948	3098	3228	3348	3468	3588
	$\hat{V}$	0.006157	0.0091	0.0111	0.0128	0.0143	0.0157	0.0171	0.0185

Table B.8 Specific Enthalpies of Selected Gases: SI Units

$\hat{H}(\text{kJ/mol})$							
Reference state: Gas, $P_{\text{ref}} = 1 \text{ atm}$, $T_{\text{ref}} = 25^\circ\text{C}$							
T	Air	O ₂	N ₂	H ₂	CO	CO ₂	H ₂ O
0	-0.72	-0.73	-0.73	-0.72	-0.73	-0.92	-0.84
25	0.00	0.00	0.00	0.00	0.00	0.00	0.00
100	2.19	2.24	2.19	2.16	2.19	2.90	2.54
200	5.15	5.31	5.13	5.06	5.16	7.08	6.01
300	8.17	8.47	8.12	7.96	8.17	11.58	9.57
400	11.24	11.72	11.15	10.89	11.25	16.35	13.23
500	14.37	15.03	14.24	13.83	14.38	21.34	17.01
600	17.55	18.41	17.39	16.81	17.57	26.53	20.91
700	20.80	21.86	20.59	19.81	20.82	31.88	24.92
800	24.10	25.35	23.86	22.85	24.13	37.36	29.05
900	27.46	28.89	27.19	25.93	27.49	42.94	33.32
1000	30.86	32.47	30.56	29.04	30.91	48.60	37.69
1100	34.31	36.07	33.99	32.19	34.37	54.33	42.18
1200	37.81	39.70	37.46	35.39	37.87	60.14	46.78
1300	41.34	43.38	40.97	38.62	41.40	65.98	51.47
1400	44.89	47.07	44.51	41.90	44.95	71.89	56.25
1500	48.45	50.77	48.06	45.22	48.51	77.84	61.09